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Hydrological modelling of Rönne å catchment for future investigation on the consequences of dam removal along Rönne å river

1. Introduction

Rönne å catchment is situated in the south of Sweden, within the border of Skåne where Rönne å river convey through it from the southeast all the way to the northwest of the catchment and discharge into Skälder bay.

Due to the consideration of restoration of ecosystem in the catchment, especially for the protection of aquatic life, the municipality of Skåne is considering removing three small hydropower dams in the Rönne å catchment (Dam Removel Europe, 2019). However, as dams are also acting as flow control structures, the removal of dams raises the concerns of potentially increasing flood risk, see Appendix 1 for the location of three dams.

Therefore, a hydrological model of the catchment is of great importance to investigate the plausible consequences of removing dams and furthermore to investigate the possible mitigation structures, such as wetlands and flood meadows in terms of reducing flood risk and restore the ecosystem.

In this study, the first step is to build a physical-based, hydrological model of the Rönne å catchment with the help of MIKE SHE and MIKE Hydro powered by DHI. In the meanwhile, ArcGIS will be employed as a preliminary tool to pre-process the raw geological, geographical, and topological data and prepare the input data for MIKE software, together with other type of data, for instance meteorological data and flow measurements within the catchment. Following that, further simulations can be carried out to investigate the consequences of dam removal.

Due to both technical and temporal issues encountered during the period, not all objectives could be met at this stage.

Therefore, the main objectives of this study would be: 1) Learn how to build a hydrological model using Mike Hydro and Mike SHE; 2) Build a functional MikeSHE model; 3) Calibrate and validate the model so that it could produce reasonable simulation results.

2. Methodology & Data

2.1. Methodology

In this study, the main tools used for the construction of the models are Mike HYDRO River and Mike SHE powered by DHI, while the pre-process of data were mainly done by the ArcGIS and occasionally Excel 2020. Furthermore, to ensure a smooth transition and combination of data between different sources, formats, platforms, the same referencing coordinate of SWEREF99_TM was used.

In addition, in this study, the preliminary models were constructed by following the integrated exercise for Mike SHE produced by DHI in 2019 (DHI, 2019) and the simulation period was in between 2014/1/1 to 2019/12/31.

2.1.1. Pre-process of data

Raw data acquired from SMHI, Lantmäterie, and SGU need to be pre-processed by ArcGIS in order to be input in the MIKE software.

All the geographical, geological and topographical data were imported in ArcGIS and masked by the shapefile of the catchment to get the landuse, soil type, DEM data within the catchment which is exactly the model domain. The applications of each data, data type and source are tabulated in Appendix 2.

2.1.2. Mike HYDRO River model

Mike HYDRO powered by DHI is an one-dimensional river model that allows users to build and execute river models for instance, river hydraulics application, flood forecasting, ecological and water quality assessment in rivers and wetland, etc (DHI, 2017).

The application of Mike HYDRO River in this study was to construct the river network in the catchment for the simulation of water flow in the catchment and subsequently to be loaded in the Mike SHE model.

Digitizing of river branches

In order to construct the river network digitally, the pre-processed shape file of water courses was imported to Mike HYDRO River directly and connections for river branches that were close to each other were generated automatically. After the import of river networks, manual adjustments were applied to connect and move the segments of branches so that an complete river links could be properly presented in the model. However, not all the branches were perfectly fitting the river presented on the background satellite image, though they did not differ a lot from the actual location, see figure 1. Therefore, to simplify the model construction processes, only the main river channel Rönne Å was manually digitized in the model with the reference of satellite image. The reason for considering the disagreement between the actual location and the imported river branches would not affect the model to a significant extent is that the DEM file used to describe the topology of the model domain in the subsequent steps has a resolution of 50 meters thus a small deviation of location would not affect the results greatly.

Besides, when generating the cross-sections of each river branches, a DEM file with a resolution of 2 m was used and cross-sections with 100-200 m width were generated so that it would cover the location where the river channels were represented in the DEM file. Therefore, it was unlikely that the profile of the river would be affected due to the mild mis-location of the river branches.

Figure 1: An example shows that the imported river branches do not perfectly agree with the location on satellite image.

Especially for the water courses, there were originally 87 branches imported to the model from the shape file as shown in Appendix 3. However, due to the heavy working load and long simulation time in one run, a simplification of the river branches was made. That was to exclude all the branches that were less than 5 km long. Besides, there were error with three branches located at the southwest part of the catchment that could not be coupled with the MikeSHE model were also neglected due to not being able to tackle the errors after various attempts. These 3 branches are relatively short; thus, it is considered as not a significant impact to the whole model at this stage. Eventually, there are in total 39 branches coupled to Mike SHE model.

Generating cross-sections

After digitizing the river networks, it is important to create cross-sections along the branches so that the profile of each river channel could be embedded in the model. So that the physical characteristics of the river networks could be presented.

In order to do that, cross-sections were primarily generated at an equal interval of every 2000 meters and with a width of 100 meters for all the tributaries based on the 2 meters resolution DEM file. In addition, by using this function, two cross-sections were automatically generated at the both ends of the branches. While, for the Rönne Å river, there was no fixed intervals but manually drew cross-section along the river channel. But a maximum interval between two cross-sections was no more than 2000 meters.

Once this was done, all the cross-sections were then edited in the software to mark the riverbanks and the lowest point in between riverbanks, as illustrated in figure 2. The red markers denote the riverbanks and the lowest point within the profile.

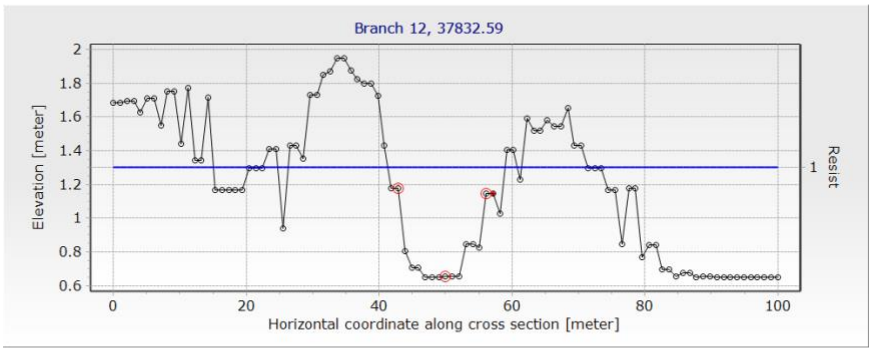


Figure 2: Cross-section at branch 12, chainage 37832.59m.

However, shallow cross-sections were observed on all the branches, as small as 0.1 meter. That is mainly due to the fact that when the satellite captures the elevation information, it measures the elevations from the water surface and the figure is subject to change temporally. Therefore, manual correction for all the cross-sections was done by arbitrarily increase the riverbanks by 2 meters, as illustrated in figure 3. Ideally, it would be better to decrease the river bed instead of increasing the height of riverbanks. Nevertheless, it would be time consuming to edit all the digit points in between riverbanks. Eventually, there are 690 cross-sections in the model.

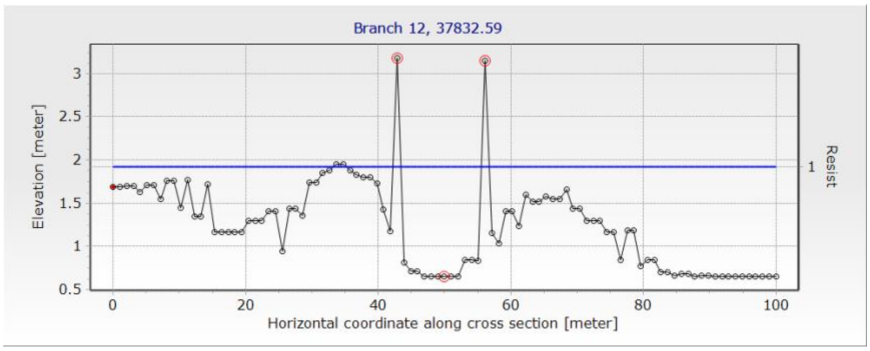


Figure 3: Arbitrarily corrected cross-section at branch 12, chainage 37832.59m.

Once the river model was successfully established, the model could be executed and modifications and improvement could be done. In order to prevent the model from running dry and subsequently led to the termination of simulation, a very small water flow of 0.05 m^3/s was introduced to each river branch.

2.1.3. MikeSHE model

Mike SHE is a more complex physical based model than Mike HYDRO. It is used to simulate the water flow in different zone, which includes overland flow, unsaturated flow, saturated flow, channel flow, etc. In another word, the soil layer is divided into three different zones in the simulation. Thus, in this model, information about for instance soil type, land use, climate and dynamic parameters are needed to build a conceptual model of the catchment so that the water flow within the catchment, especially the river channel could be simulated.

The user interface of Mike SHE is more complicated than of Mike HYDRO and it requires more information to simulate the water flow in the model domain. For the detail simulation specifications of the model, it can be found in the Mike SHE exercise (DHI, 2019) such as time step control, iterations, saturated sickness, etc. Although, for the establishment of model, most of these fundamental and kinetical setting of parameters were directly adapted from the exercise, unless otherwise stated.

Apart from the simulation mechanics, the model requires different data as input, including climatical, topological, geological and geographical data.

Furthermore, to get a stable running model, it is suggested that a hotstart from the end of a previous model run is preferred as the initial condition for the subsequent model run. And normally, the hotstart at the end of a dry period would be preferred as it could provide a steadier initial condition especially in the soil layers.

Therefore, judging by the annual precipitation, 2015/1/1 to 2016/3/25 was selected as a pre-run and the hotstart date was set at 2016/3/25, while 2016/3/25 to 2017/5/30 was selected as the calibration period. After proper calibration, the model would run under the calibrated condition. Consequently, 2017/5/30 to 2019/12/31 was chosen for the validation period.

2.1.4. Calibration and validation

To calibrate the model, several observation data alone the main channel and tributaries were added to the Mike SHE.

Primarily, many attempts were made to calibrate the model and the focus is on achieving satisfying calibration results at least for the main channel. The preliminary targeting value is for the sample correlation coefficient R to achieve at least 0.85. During the calibration, normally one parameter was changed at a time and then move on the next parameter, occasionally several parameters were adjusted at the same time.

The main parameters chosen for the calibration processes are hydraulic conductivity (both horizontally, Kh and vertically, Kv), Manning's number (m), drainage level, drainage time constant (Td), air temperature correction and

There were several parameters that were used in the calibration process to better fit the observation data.

2.2. Data

To properly establish the model, the first step is to collect data that would describe the physical characteristics of the catchment from various sources. Thanks to the well-developed accessibility of open data in Sweden, majority part of the data could be collected without asking for special permission.

2.2.1 Geological, geographical & topographical data

Geological data which are used to describe the geology and geography of the catchment are acquired from several sources, which include the digital elevation, soil types, land use type, vegetation coverage, watercourses. Among these, it can be divided into two categories that were used in either the MikeHYDRO or in MikeSHE model, as presented in Appendix 2.

2.2.2 Meteorological data

Meteorological data including daily air temperature, global radiation and precipitation which are needed in Mike SHE model to describe the climate of the catchment. Therefore, relevant data were acquired from SMHI website. Although, there are in total 8 active meteorological stations in the catchment area, in the preliminary stage of the model establishment, daily precipitation rate at the Klippan meteorological station was used. This station is situated at the downstream direction of the river close to the center part of the model domain. Details regarding data used in the model are presented in table 1. Note, each item used in the model originally have different duration length.

Table 1: Meteorological data used in the model, daily average value..

Item	Station	Duration	Note
Air temperature, °C	Hörby A	1995/08/01-2020/12/31	Air temperature Horby A
Precipitation, mm/d	Klippan	01/01/1945-2020/12/31	Precipitation data at Klippan
Global radiation	Lund	2008/01/01 - 2020/09/31	Assuming annual evapotranspiration remains the same

Among these, the global radiation was used to estimate the evapotranspiration potential in the catchment.

In order to estimate the evapotranspiration potential, the average monthly potential evapotranspiration rate of Malmö for the period of year 1961-1978 was used. Subsequently, the monthly values are distributed throughout the month on an hourly basis, which were preliminarily based on the proportion of the hourly global radiation in a day. That is every year has the same annual evapotranspiration potential but with different distribution throughout the simulation period. The reference monthly evapotranspiration rates are presented in Appendix 4.

All the meteorological data were set as spatially uniform distributed over the catchment, that there was only temporal variation and neither temperature nor precipitation was corrected based on elevation.

2.2.3 Observation data

In this study, observation data of flow measurements at four stations are available for calibration and validation. Among these, two observation stations are situated at the upstream and downstream part of the main channel while the other two are situated at the down stream part of Branch 11 and 12, respectively. The location of each observation point is presented in table 2.

Table 2: The location of each observation point

Name	Type	Branch name	Chainage
Tributary Dam_Klippan2	Discharge	Branch 12	37573
Downstream Dam	Discharge	Main Channel	83252.9
Upstream	Discharge	Main Channel	24905.6
Tributary near outlet	Discharge	Branch 11	36170
HYPE Outlet	Discharge	Main Channel	125630

Note: The chainage of each observation point is not the exact location, but very close to the exact location. The exact location of each observation point is expressed as coordinates and the exact locations are illustrated in the figure in Appendix 5.

Although there is no flow measurement at the river mouth, it is possible to use the simulation results from HYPE model. Thus, a discharge observation can be included in the calibration. See Appendix 5 for the location of the discharge point.

Above all, there are in total five observation data included in the MikeSHE model for the calibration purpose.

2.2.4 Calibration parameters and validation

During the calibration processes, with references from Hävermark (2016) and MikeSHE user manual (DHI, 2017), several parameters in the model were calibrated and are presented in table 3:

Table 3: Calibration parameters

Parameters	Original value		Calibration
K_h	1.00E-04		1e-04 to 1e-05
K_v	0.0001		
Manning's number, overland flow	Over land flow	2	2 to 17
	Branche 12	30	40, while gloable Mannig's number was 30
	Main channel	30	Three points starting from upstream at chainage 0 and increasing gradually from 20 to 30, gloable Manning's number was 40
Drainage time constant	5.60E-08		5.6e-08 to 1.5e-07/s

drainage level	-0.5m	-0.5 to -1m
Elevation correction	Air temperature	With correction and apply both with or without dry and wet ellapse
	Precipitation rate	With correction, default correction value applied

3. Results and discussion

3.1. Mike HYDRO RIVER

A river network with 39 river branches in total was established in Mike HYDRO River which represented the majority of river branches and the profile of each river branches within the catchment, as shown in figure 4.

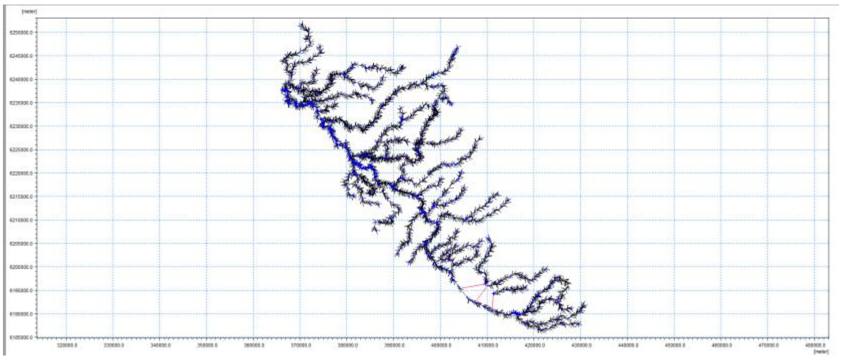


Figure 4: River branches in the Rönne Å catchment in the model.

Adjustments such as moving, deleting or editing cross-section profiles were made to make the profile of the river consistent, see figure 5.

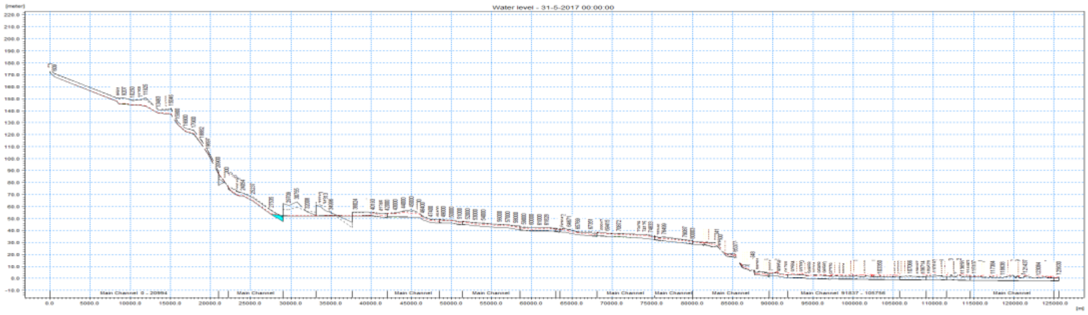


Figure 5: River profile of Main branch (Rönne Å river)

There are several cross-sections arbitrarily drew at the furthermost upstream of tributaries where the rivers were too narrow, shallow and shaded by the surrounding vegetations, to the extent that the river courses could not be traced or recognized from the satellite image.

In addition, the cross-sections at where the dams are located were generated using the bathymetric measurement with a resolution of two meters, thus cross-sections at the river bank of dams were not increased by two meters as mentioned in section 2.1.2., as those were the field measurements of the river segments between dams, as shown in figure 6.

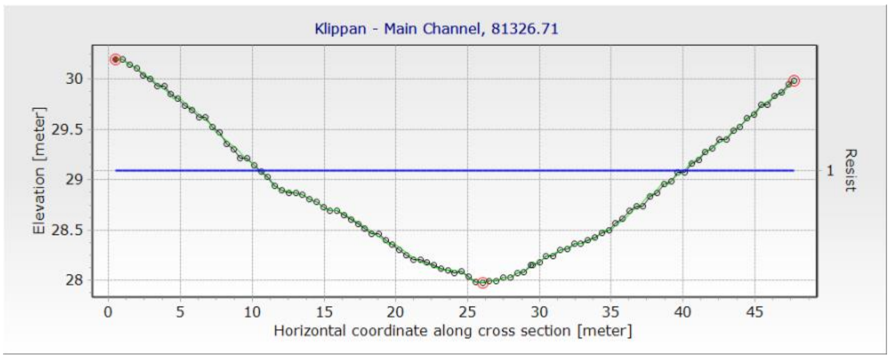


Figure 6: Cross-section between dam Klippan and Stackarp (Rönne Å river)

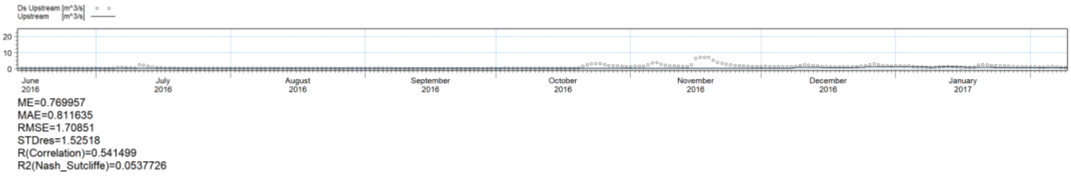
It is worth noting that even though the Hydro River model could run successfully, there are still some improvements needed to be achieved and will be discussed later. Whereas the most important part is to improve the river profile.

3.2. Mike SHE catchment model

With repeatedly correction and modification, the MikeSHE model was successfully launched and executed without abnormal terminations. Although there are a lot of warnings in the simulation logfile, it was considered to be negligible at this preliminary stage.

In order to obtain a better and steady simulation, a model was ran for the period from 2015/01/01 to 2016/03/25. The reason for choosing this period was due to the fact that it was the end of a rather dry season so that the hotstart can provide a steady initial condition in the soil layers especially for the followed model run. And according to the instruction from the MikeSHE exercise in 2019, a proper model run as a hotstart should be a year or two (DHI, 2019).

With careful examination of preliminary results from the first calibration model run, it was observed that the simulated flow was in general lower than the observed flow at all observation points. Especially during the peak flow events, the flows were significantly underestimated, as shown in figure 7.



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ME=0.769957
MAE=0.811635
RMSE=1.70851
STDres=1.52518
R(Correlation)=0.541499
R2(Nash_Sutcliffe)=0.0537726
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Figure 7: Observation vs. simulated flow at upstream of Main channel, chainage

In order to calibrate the model to fit the observation data, several parameters mentioned in section 2.2.4 were chosen for the calibration.

3.3. Model calibration

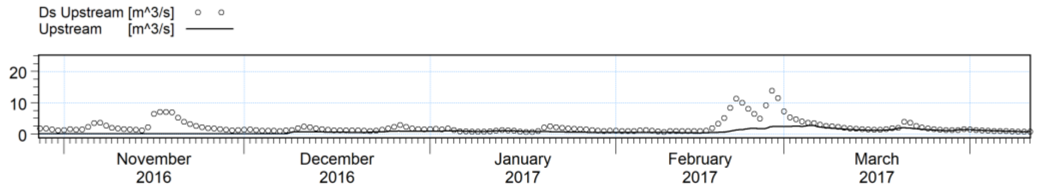
After a successful model run with hotstart on 2016/03/25 and a simulation between 2016/03/25 to 2017/05/31, the statistics between observation and simulation were obtained.

It was obvious that the simulation results had a unsatisfactory to poor agreement with the observations, especially the figures at the upstream end, see table 4:

Table 4: Model run with hotstart before calibration, (Cali 1)

Cali 1	Load Hotstart from 2016/03/25	
Name	R(Correlation)	R2(Nash_Sutcliffe)
Tributary Dam_Klippan2 (Branch 12, 37832.59)	0.81	0.18
Downstrem Dam (Main Channel, 83040.96)	0.85	-0.19
Upstream (Main Channel, 25236.96)	0.54	0.05
Tributary near outlet (Branch 11, 36048.55)	0.87	0.14
HYPE Outlet (Main Channel, 125629.6)	0.91	0.16

While looking into the plots between observations and simulation, it was noticed that the trend of simulations were in general consistent with the observations though it was almost always lower than the observed value. Moreover, most of the simulated value could not simulate for the peak events well, and either it was way lower than the observation or no peaks at all, see example in figure 8 to figure 10.



ME=0.769957
MAE=0.811635
RMSE=1.70851
STDres=1.52518
R(Correlation)=0.541499
R2(Nash_Sutcliffe)=0.0537726

Figure 8: Observation vs. simulation plot during 2016/11 to 2017/03 at upstream

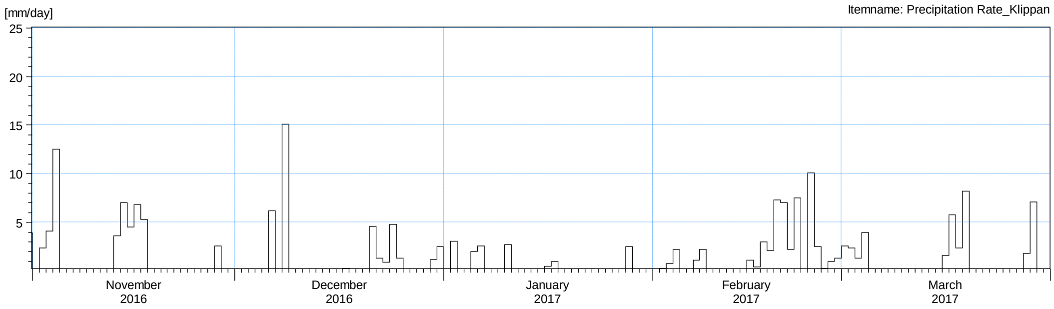
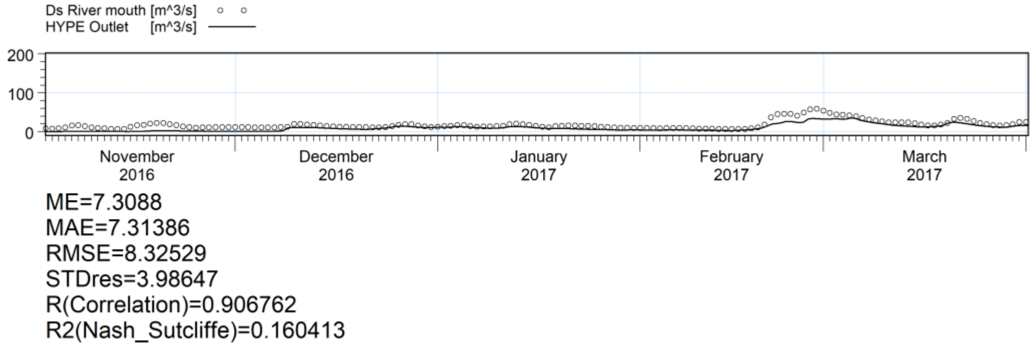


Figure 9: Observation precipitation rate at Klippan station during 2016/11 to 2017/03



ME=7.3088
MAE=7.31386
RMSE=8.32529
STDres=3.98647
R(Correlation)=0.906762
R2(Nash_Sutcliffe)=0.160413

Figure 10: Observation vs. simulation plot during 2016/11 to 2017/03 at river mouth (HYPE)

Thus, the objective for the calibration was to increase the peak flow, increase the flow rate in general therefore relevant parameters were altered to get a better simulation result. Such as increase the drainage time constant, decrease the surface roughness (Manning's number), decrease the permeability of soil layers (decrease Kv, increase Kh) of the model domain so that water could drain faster to the river.

However, even after more than 40 trials of calibration, the correlation of upstream observations on the main channel still could not be improved significantly. While comparing the precipitation records with the observation flows, it is obvious that at the flow peaks, there were often heavy rainfall events associated closely before the peak (e.g., the highest peak around 2017/02/22). However, the meteorological station was situated far downstream, thus it was not a surprising outcome that even with the elevation correction the flow could not be corrected to a satisfying extent. Not to mention that there are other factors and assumptions made in the model that would affect the simulation of flow, such as the condition of soil layers.

After various scenario attempts and discarded many unreasonable results, a best be not satisfying calibration could be obtained (Cali 14) at this stage, see table 5.

Table 5: Statistics of final calibration model and validation model

Cali 14	Load Hotstart from 2016/03/25	Vali 1	Load Cali 14 as hotstart

Name	R(Correlation)	R2(Nash_Sutcliffe)	R(Correlation)	R2(Nash_Sutcliffe)
Tributary Dam_Klippan2 (Branch 12, 37832.59)	0.81	0.19	0.84	0.58
Downstrem Dam (Main Channel, 83040.96)	0.84	-0.18	0.88	0.70
Upstream (Main Channel, 25236.96)	0.55	0.07	0.84	0.64
Tributary near outlet (Branch 11, 36048.55)	0.87	0.15	0.89	0.55
HYPE Outlet (Main Channel, 125629.6)	0.91	0.17	0.92	0.74

In this calibration, the final settings for parameters that were used in calibration were listed below and most of these values were reset to default since altering could not produce an improved result rather than a compromised or not changed result statistically, see table 6.

Subsequently, this scenario was used as hotstart while keeping all the parameter settings for validation period of 2017/5/31 to 2019/12/31.

As the result shows, see table 5 that the simulated values fit the observation values better during the validation period that all the R values and R^2 improved, while only the observation point upstream did not achieve a correlation no smaller than 0.85.

Table 6: Parameters for final calibration scenario

Parameters		Original value	Final value
Kh		1.00E-04	1.00E-04
Kv		1.00E-04	1.00E-04
Manning's number, overland flow	Over land flow	2	5
	Branche 12	30	30
	Main channel	30	30
Drainage time constant		5.60E-08	5.60E-08

drainage level		-0.5m	-0.5m
Elevation correction	Air temperature		With correction but without ellapse
	Precipitation rate		With correction

3.4. Sensitivity analysis

During the latest calibration batch, several parameters were tested. Among those, the model was not sensitive to the change of drainage level which decreased from -0.5m to-0.8m, relative to the ground, and also not sensitive to the change of hydraulic conductivity both vertically and horizontally. However, the model is sensitive to the change of drainage time constant which gives a significant increase in flows in general.

4. Conclusions

Although, many calibration scenarios were setup and ran, there was no single model run that could provide satisfying simulation results that is achieve at least for all the main channel observation points to have a R value no smaller than 0.85. Among these observation points, the HYPE simulated observations correlates better to the Mike SHE simulations which in general achieved a R value of more than 0.9. On the contrary, the observations at the upstream end (chainage 24905.6), were poorly fitted by the simulations, which in general gave a R value between 0.50 to 0.60 in almost all the calibration scenario.

There are several reasons for the calibration objectives could not be fully met. Firstly, and most importantly is the precipitation data used in the model which is the only water input in this model. As there are eight meteorological stations distributed in the catchment, using records from one station is obviously not enough especially given the fact that the elevation of the catchments varies dramatically from around 20 meters to 170 meters which will affect the distribution of precipitation significantly.

Secondly, the Manning’s number in the catchment is assumed to be uniformly distributed which is obviously not the case in the reality. And Manning’s number would vary significantly between different landuse. Especially all the river channels are assumed to have the same roughness in the simulation, thus it also brings uncertainties into the model.

Thirdly, the soil layers for different soil type in the unsaturated zone were assumed to have the same depth and the depth was set according to the tutorial which might not be reflecting to the reality in the catchment.

Besides, the potential evapotranspiration rate was assumed to have a constant yearly value and the evapotranspiration varies within the year based on the proportion of global solar radiation of the day to the month. With the rapidly shifting of climate and extreme weather events, such assumptions will not be valid in a later stage of the simulation that is to forecast for the future scenarios.

In addition, even though the MikeHYDRO River model could be run without any errors or warining at this stage, there are still quite some spaces for improvements, such as acquire more real bathymetric measurements to be used to create more reasonable cross-sections along the main channel.

And moreover, to adjust and improve the river networks by including some more branches so that the fitness of simulations to the observation points situated at the tributary could potentially be improved.

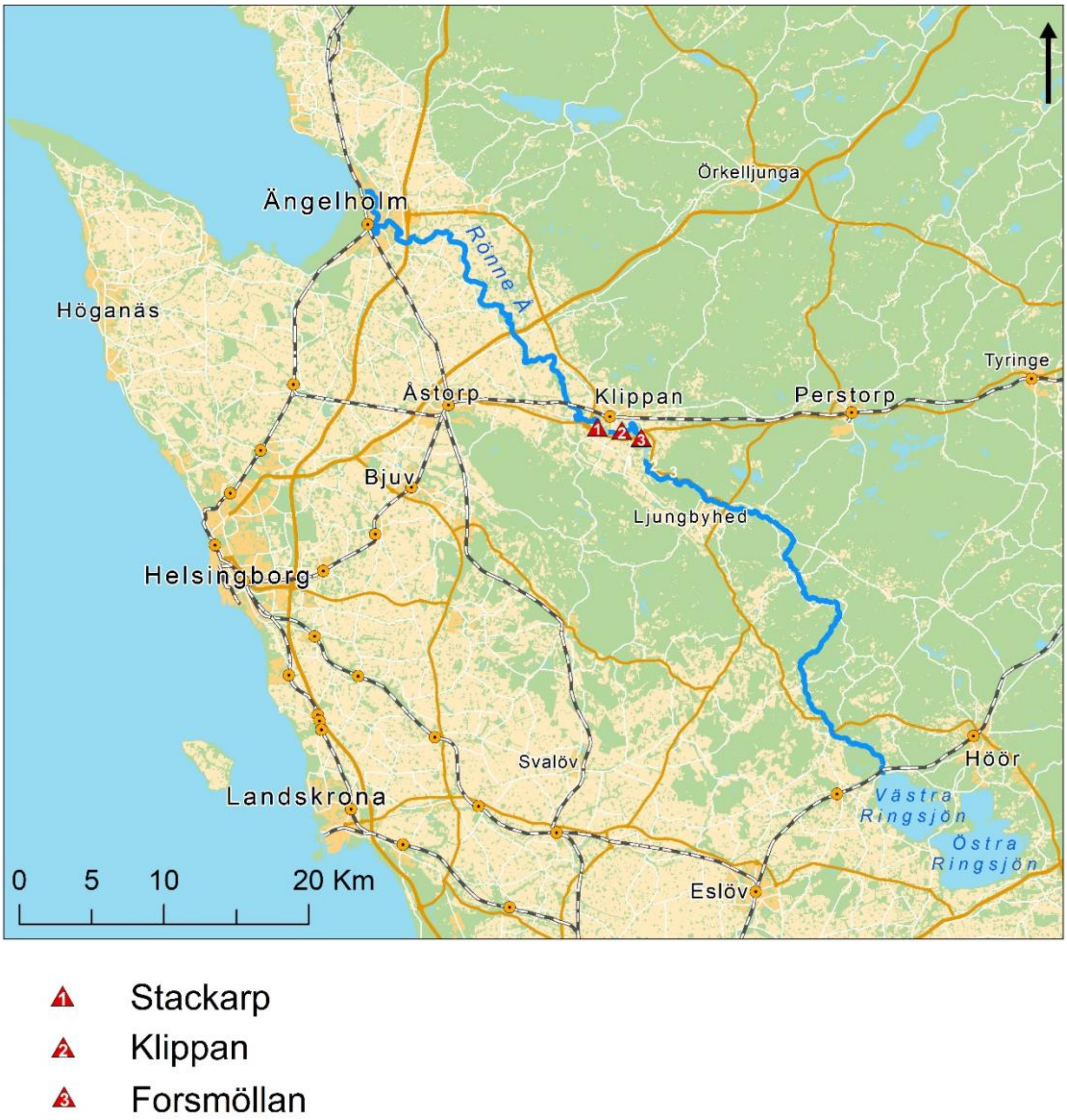
To sum up, there are a lot of improvements that could be done to this model, it is recommended to first simplify the setup of the model by update the Manning's number based on the main types of landuse and create a spatially varied Manning's number as an input to the mode.

To optimizing the classification of landuse types and soil types in the further models so that firstly to shorten the simulation duration because of too many details are in the current model that increased the time for each simulation.

Reference:

DHI, 2019. MIKE SHE Fully Integrated Exercises Step-by-step training guide 139.
DHI, 2017. MIKE SHE User Manual, Volume 1: User Guide.
Europe, D.R., 2019. Dam removal planned in Rönne å River in the south of Sweden. Dam Removal. Eur. URL https://damremoval.eu/dam-removal-planned-in-ronne-a-river-in-the-south-of-sweden/ (accessed 6.14.21).
Hävermark, S., 2016. Modelling the effects of land use change on a peri-urban catchment in Portugal. Uppsala University, Uppsala.

Appendix 1: Three dams of concern for the removal along the river



Appendix 2: Data used in Mike HYDRO & Mike SHE

Appendix 2a: Data used in Mike HYDRO River

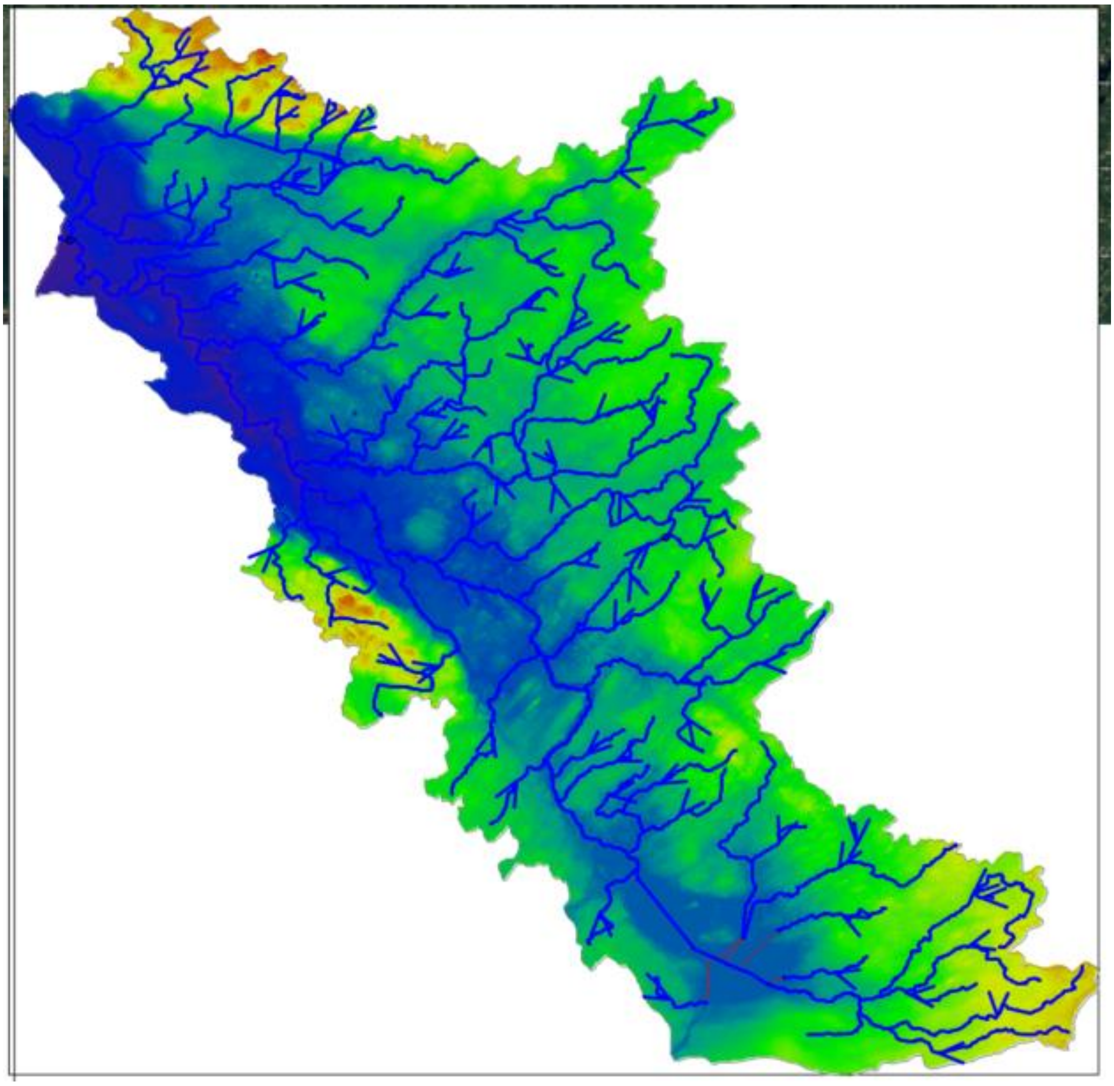
Name	Format	Application
Background map	Bitmap	Background of the model
Catchment shapefile	Shape file, polygon	Define model domain
DEM 2m	Digital elevation data	Define the river cross-sections
Water courses	Shape file, polyline	Define the river network
Klippan Bathymetry	ASC file	Define the bathymetry of three Dams alone the main channel

Appendix 2b: Data used in Mike SHE

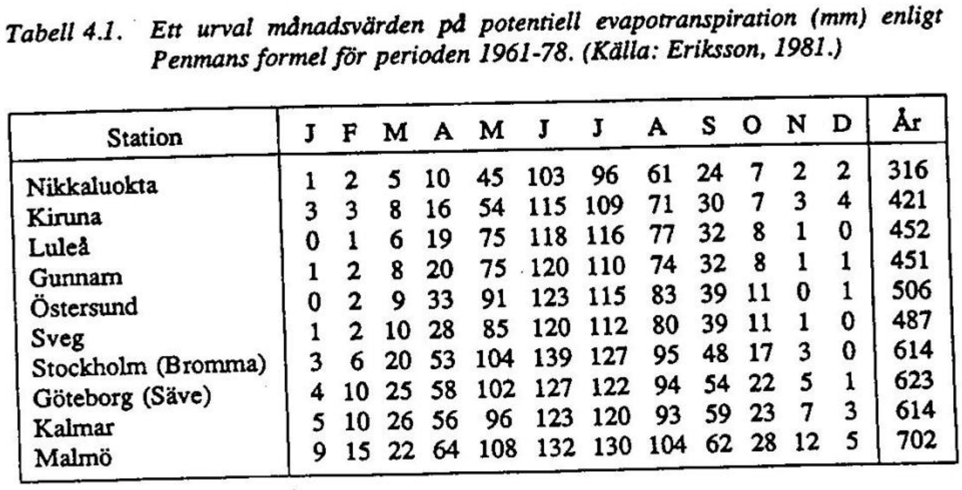
Item	Station	Application	Note	Source
DEM 2m	Digital elevation data	Resampled to 50m resolution, define catchment topography	-	Lantmäterie
Land use	Shape file, polygon	Define the land use in the catchment area	-	Lantmäterie
Well depth	Shape file, point	Scattered point data, define the lower bottom level of aquifer in SZ.	Scatter points only, search radius of 3km was applied to cover the model domain	SGU
Groundwater level	Shape file, point	Scattered point data, define the groundwater level below the ground. Define initial potential head in SZ.		SGU
Soil type	Shape file, polygon	Define the soil type in or near the ground surface	Various soil type classified into soil types that are available in the database of MikeSHE	SGU

River and lakes	Mike hydro model file (.mhydro)	Define the river networks and its dynamic in the modol domain	The outlines of the river courses are not following the exact location of the river channel. Small deviations	Mike HYDRO River

Appendix 3: River branches originally imported from water course shape file



Appendix 4: Reference monthly evapotranspiration rate, figures of Malmö were used (Eriksson, 1981).



Tabell 4.1. *Ett urval månadsvärden på potentiell evapotranspiration (mm) enligt Penmans formel för perioden 1961-78. (Källa: Eriksson, 1981.)*

Station	J	F	M	A	M	J	J	A	S	O	N	D	År
Nikkaluokta	1	2	5	10	45	103	96	61	24	7	2	2	316
Kiruna	3	3	8	16	54	115	109	71	30	7	3	4	421
Luleå	0	1	6	19	75	118	116	77	32	8	1	0	452
Gunnarn	1	2	8	20	75	120	110	74	32	8	1	1	451
Östersund	0	2	9	33	91	123	115	83	39	11	0	1	506
Sveg	1	2	10	28	85	120	112	80	39	11	1	0	487
Stockholm (Bromma)	3	6	20	53	104	139	127	95	48	17	3	0	614
Göteborg (Säve)	4	10	25	58	102	127	122	94	54	22	5	1	623
Kalmar	5	10	26	56	96	123	120	93	59	23	7	3	614
Malmö	9	15	22	64	108	132	130	104	62	28	12	5	702

Appendix 5: The location of each observation point.